



University of
Pittsburgh

Swanson School
of Engineering

Effect of Extreme Superloads on Pavements in Pennsylvania

Julie Vandebossche, PE, PhD



CENTER FOR
**Sustainable
Transportation**
INFRASTRUCTURE





Courtesy of Pennsylvania Department of Transportation

- GVW exceeds 200 kip
- Unique axle groups
- High number of wheels per axle group

- Effect of SL on pavements?
- Current pavement performance tools cannot account for effect of superloads

Objective:

Quantify the effect of SLs on:

Pcc pavements

- Fatigue cracking
- Damage to doweled joint

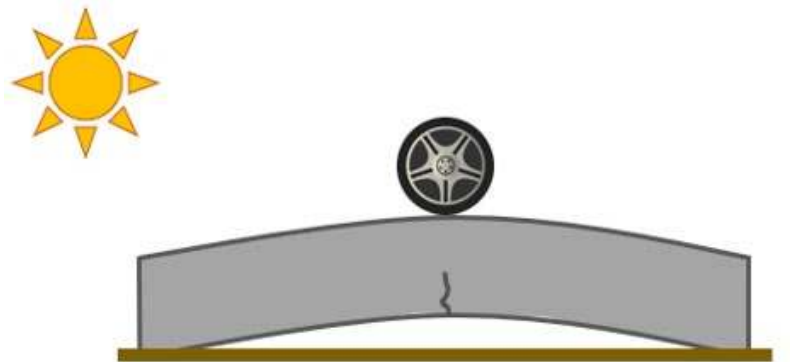
HMA pavements

- Fatigue cracking in asphalt pavements
- Rutting in asphalt pavements

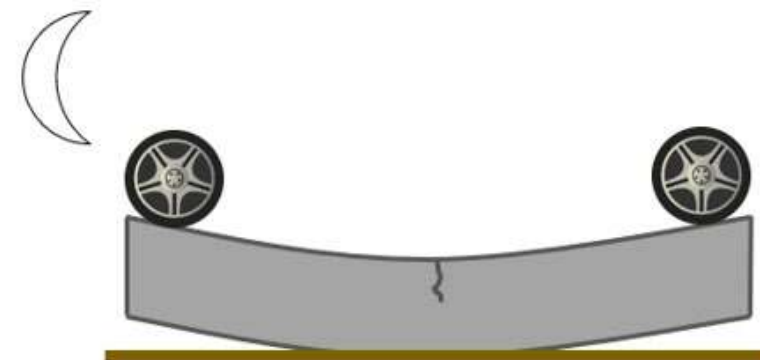
Effect of SLs on PCC fatigue cracking

PCC fatigue cracking

- Caused by repeated vehicle and environmental loading
- Location of crack development dependent on load application, temperature gradient

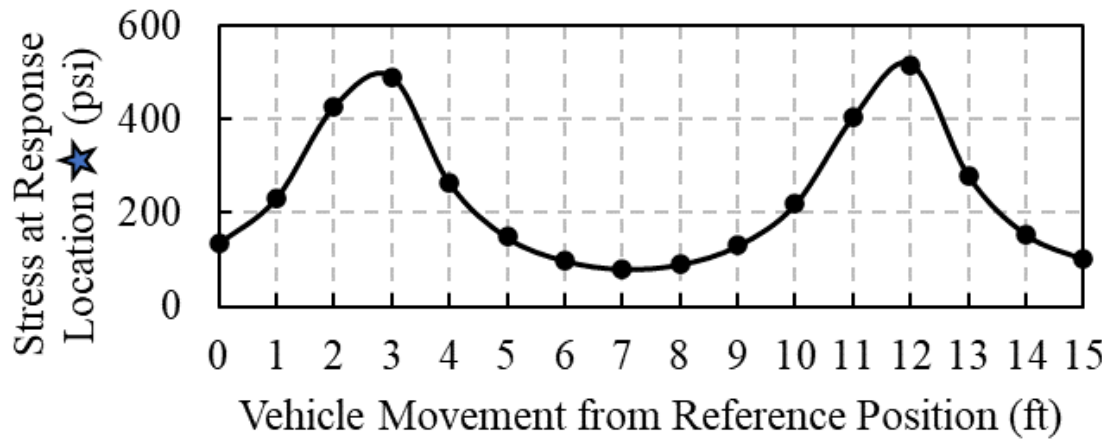
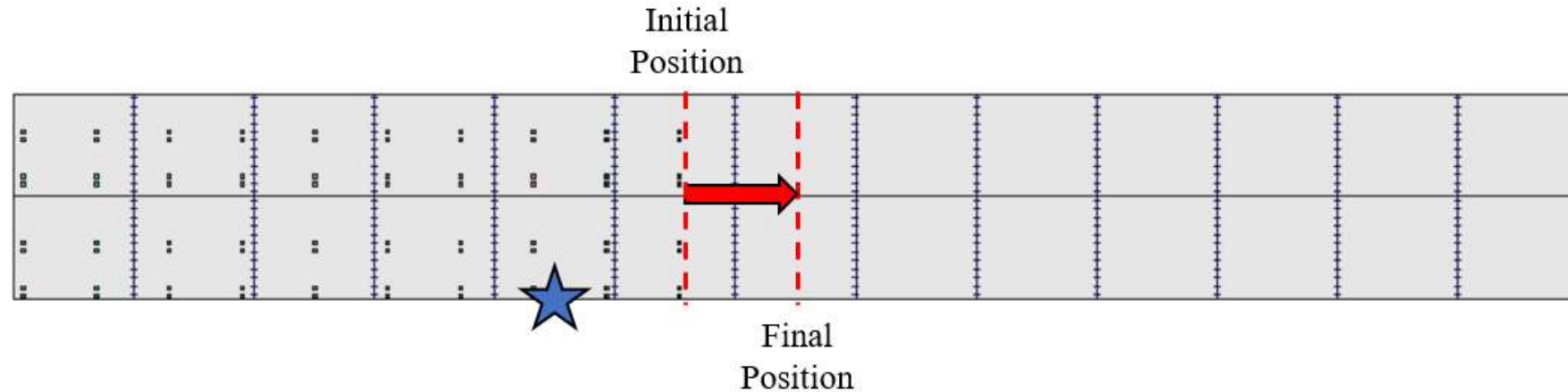


Positive Temperature Gradient

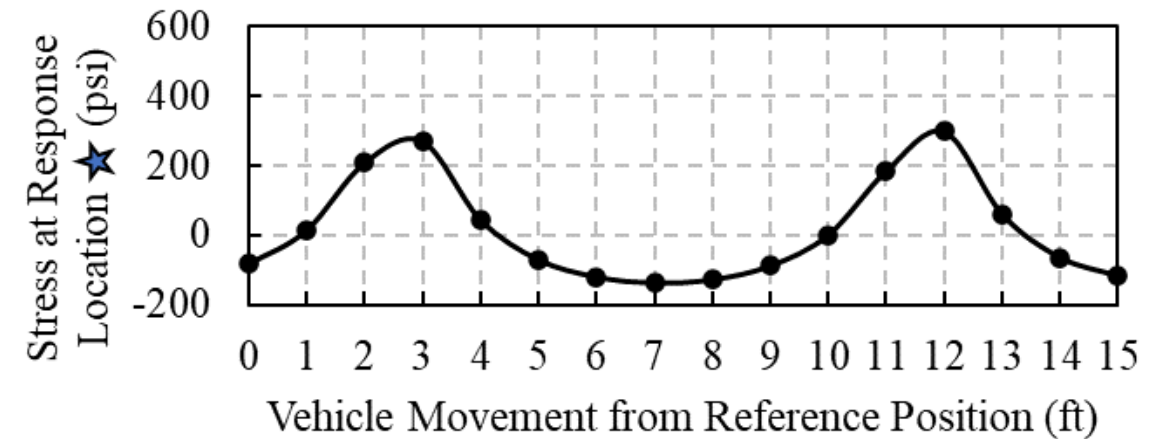


Negative Temperature Gradient

Computational modeling



ELTG = +3 °F/in



ELTG = 0 °F/in

Typical 28 day MOR = 700 psi

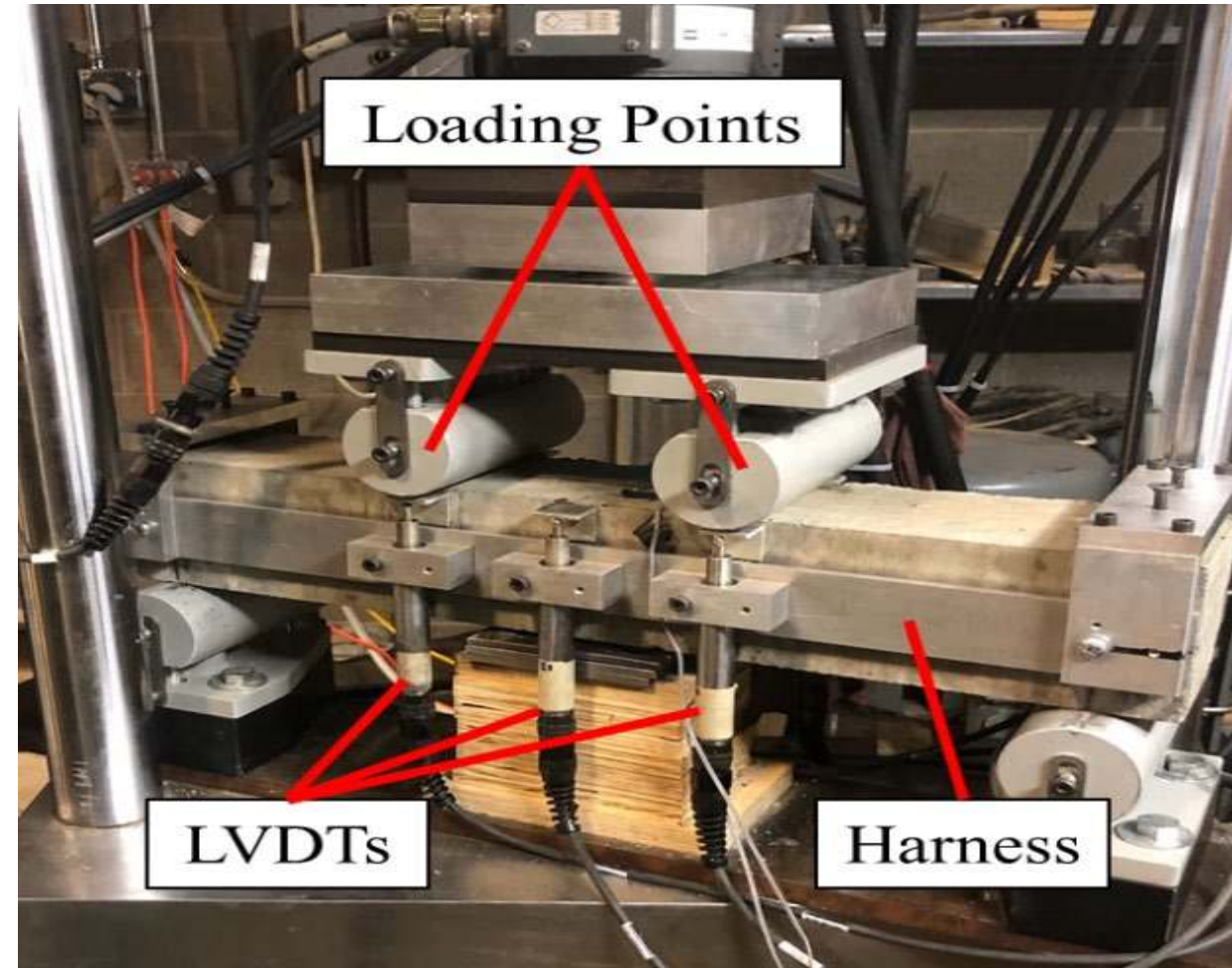
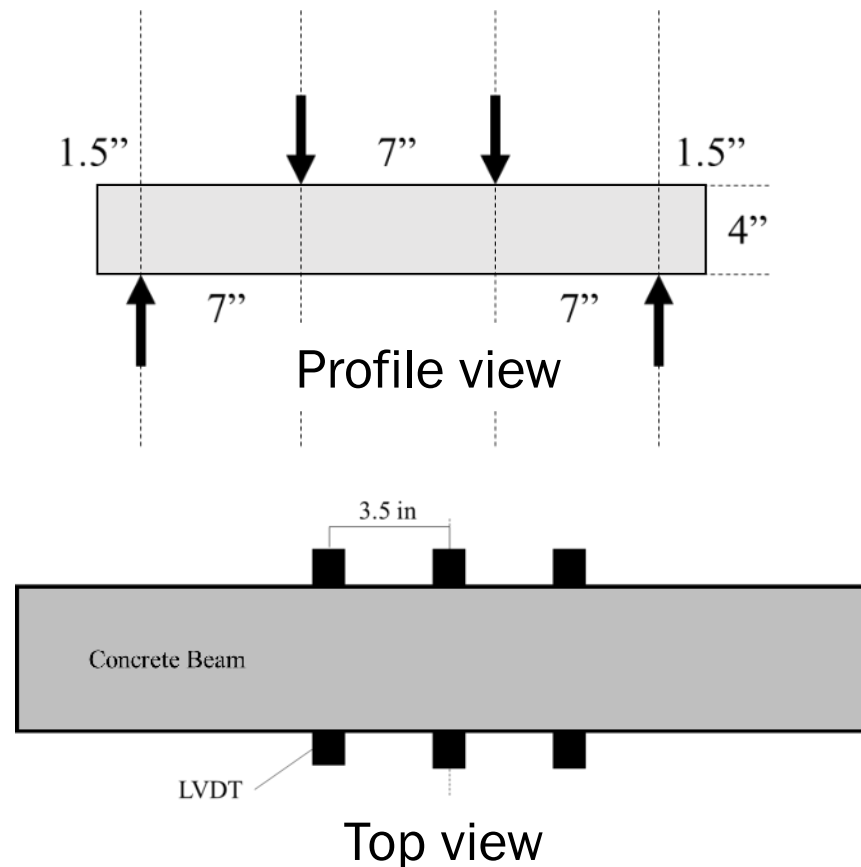
Fatigue life consumed (%)

Significant damage with high positive ELTG

SL case_slab thickness_ shoulder type	ELTG = +3 °F/in		ELTG = 0 °F/in	
	Considering peak stress	Considering stress range	Considering peak stress	Considering stress range
SL1_8_A	100	100	0.1	<0.12
SL1_10_A	1.4	0.1	-	0.0
SL1_8_C	3.0	0.1	-	0.0
SL2_8_A	4.6	0.3	0.0	0.0
SL2_10_A	0.2	0.0	-	0.0
SL2_8_C	0.8	0.0	-	0.0
SL3_8_A	4.6	0.4	0.0	0.0
SL3_10_A	0.2	0.0	-	0.0
SL3_8_C	0.1	0.0	-	0.0
SL4_8_A	80	19	0.0	0.0
SL4_10_A	1.2	0.1	0.0	0.0
SL4_8_C	0.8	0.0	-	0.0
SL5_8_A	11	1	0.0	0.0
SL5_10_A	0.2	0.0	-	0.0
SL5_8_C	0.2	0.0	-	0.0

A = Asphalt (untied) shoulder, C = concrete (tied) shoulder

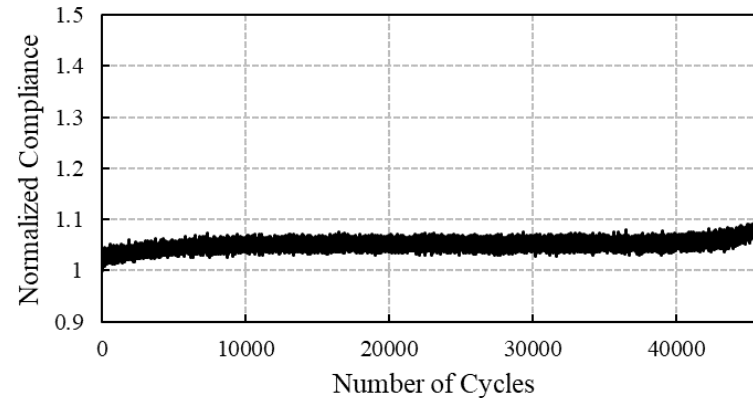
Four-point bending fatigue testing



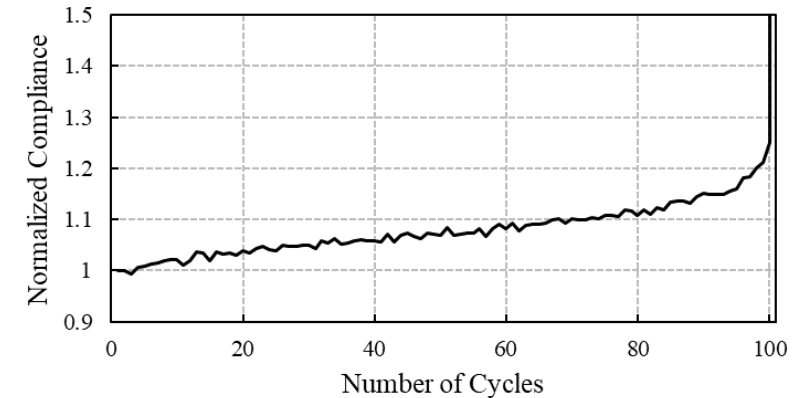
Constant amplitude results

Stress ratio = SR
 $SR = \frac{\text{Stress}}{\text{Strength}}$

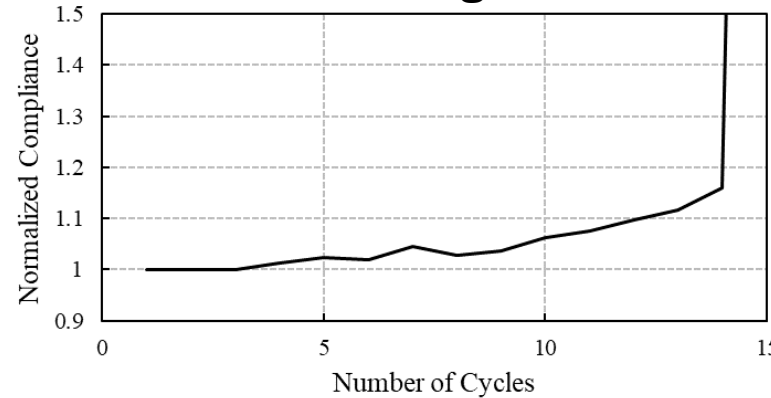
SR = 0.7, Single axle



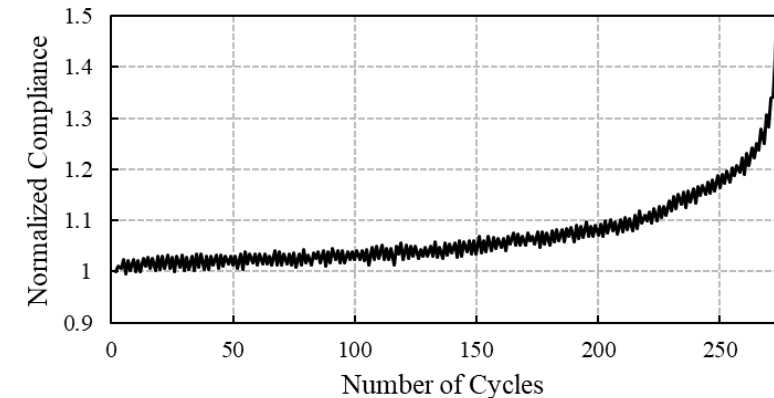
SR = 0.8, Single axle



SR = 0.9, Single axle



SR = 0.9, Tandem axle

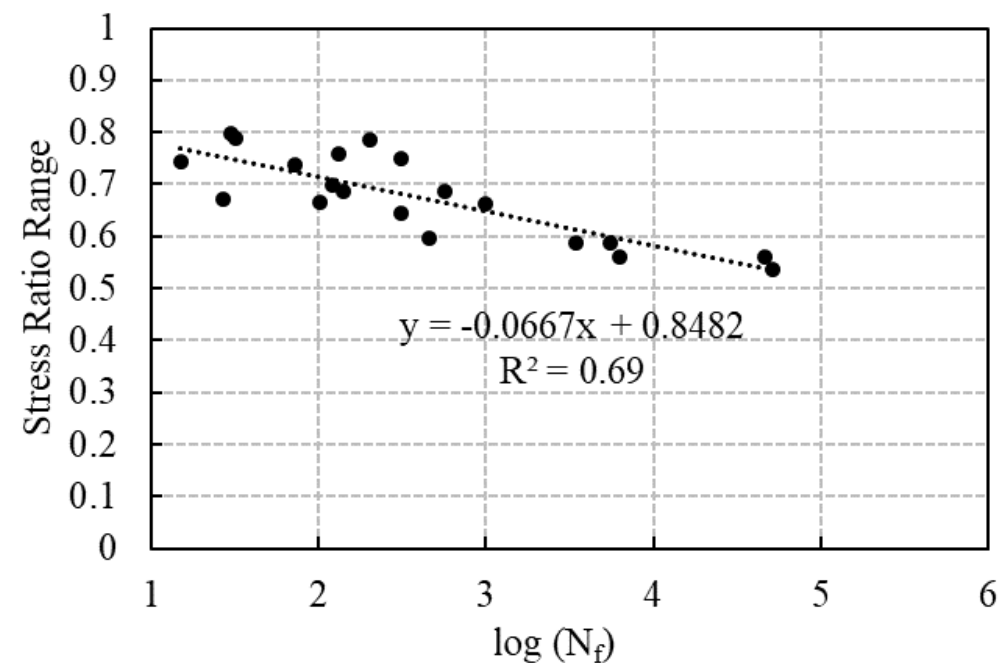
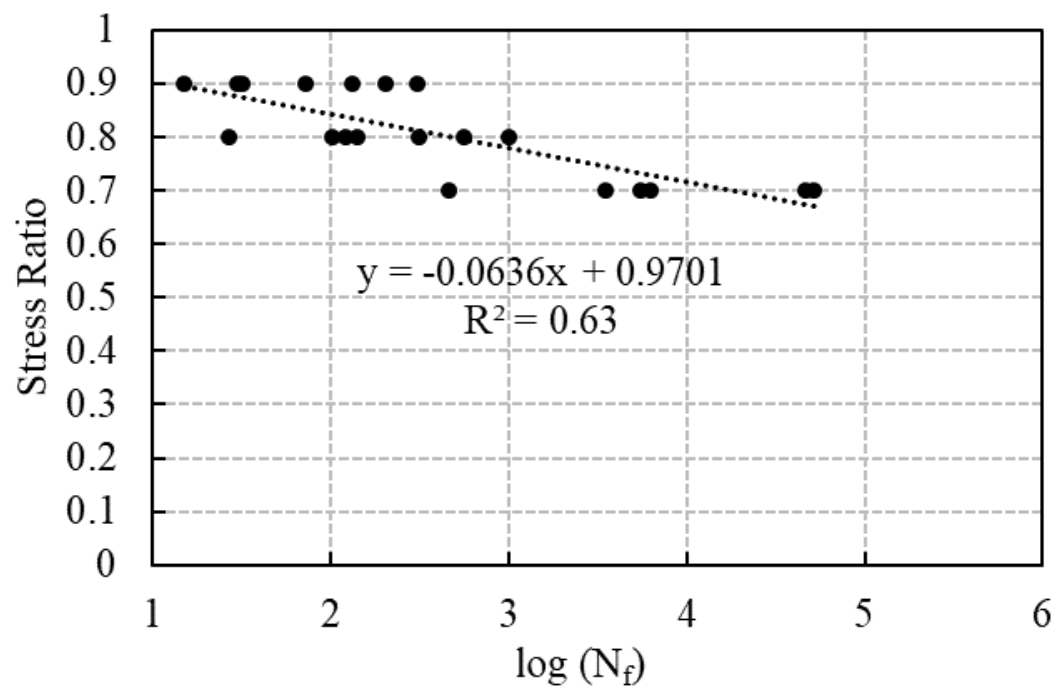


Damage accumulates non-linearly!

Effect of stress ratio

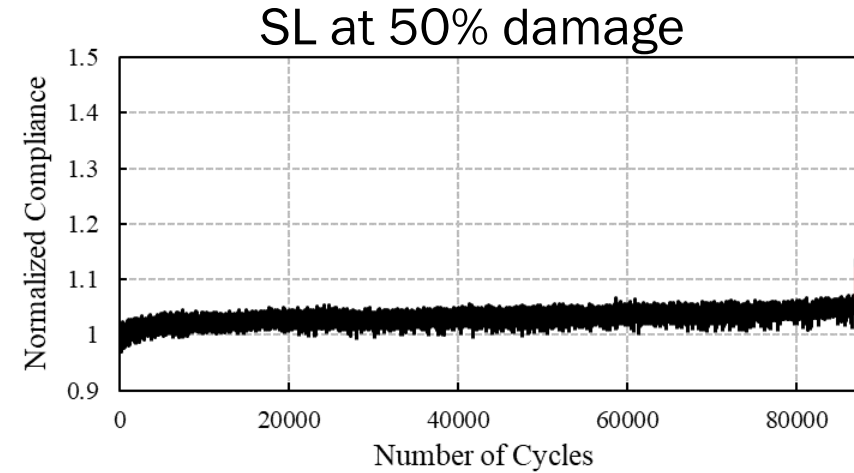
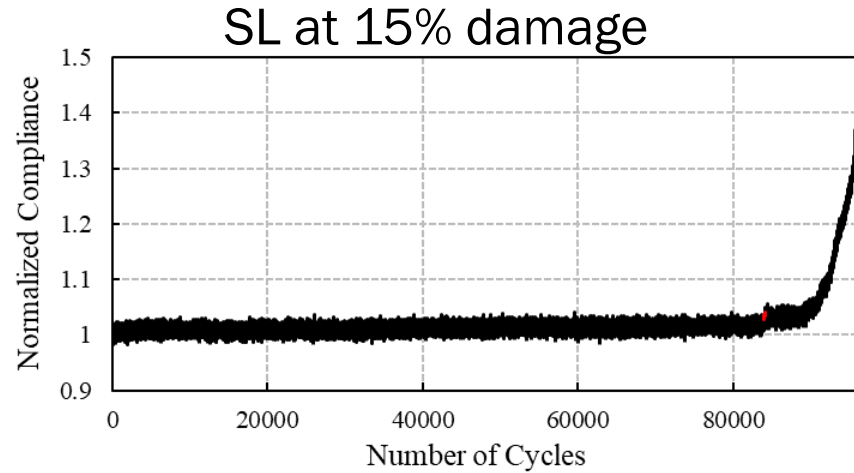
Stress ratio = SR

$$SR = \frac{\text{Stress}}{\text{Strength}}$$

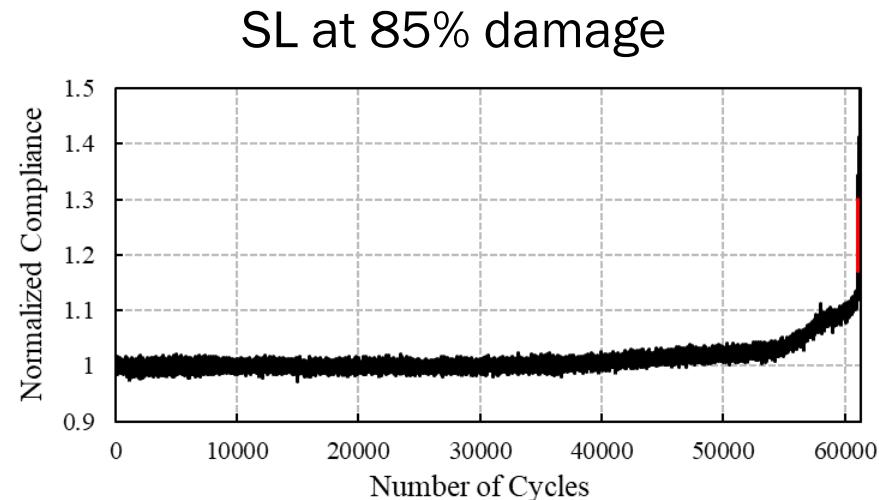


Higher stress ratios results in fewer loads to failure

Effect of pavement condition



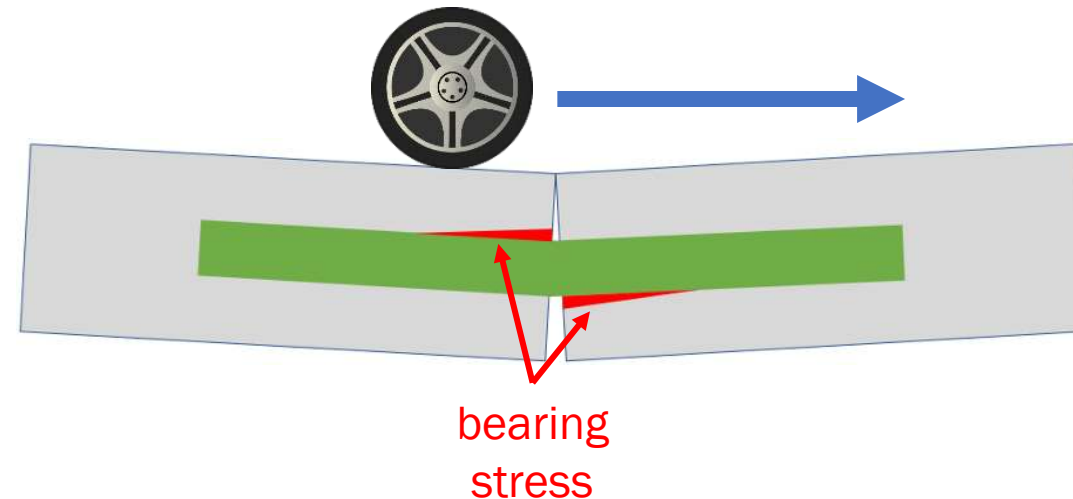
Damage caused by SL is larger when applied to pavements with more damage (older pavements)



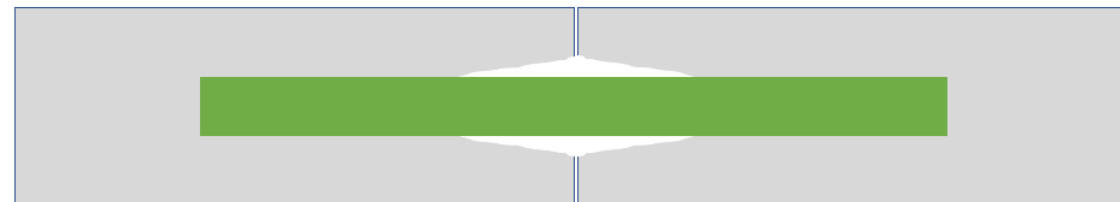
- Non-linear increase in the fatigue damage
- Increase in damage caused by single SL pass depends on the existing damage state
- Traditional S-N curve and linear damage hypothesis approach to predict fatigue damage for an overload stress can underestimate the damage caused by a SL

Effect of SLs on doweled PCC joint performance

Vehicle loads induce **bearing stresses** in concrete surrounding the dowel

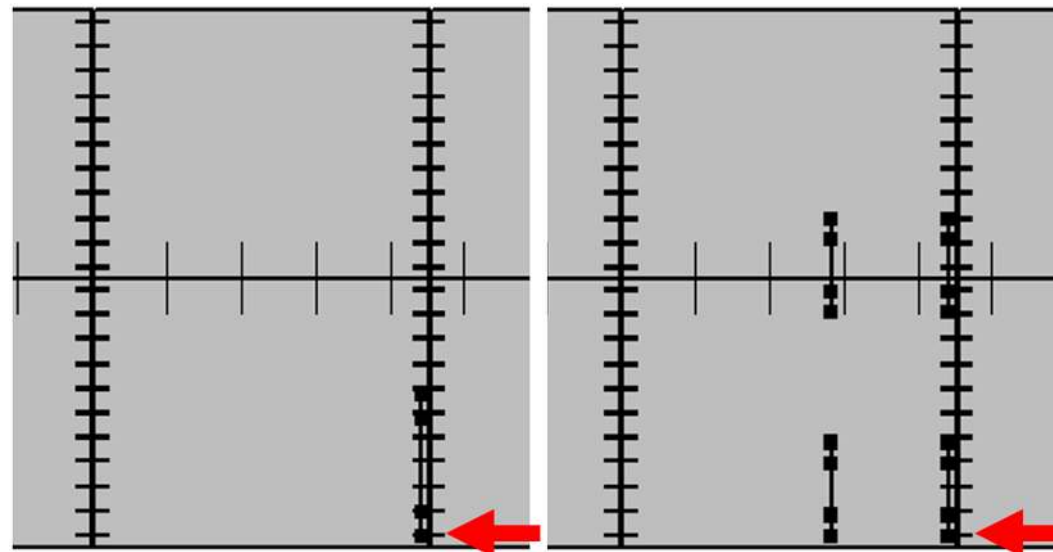


Repeated load applications can potential damage the surrounding concrete, resulting in loss of performance



Objective: Quantify bearing stress = F (dowel dia., axle load and type, temp. gradient, slab thickness)

- Typ. SL axle configurations modeled using EverFE



Single and tandem axles placed in critical position relative to indicated dowels

Critical bearing stress

Allowable bearing stress

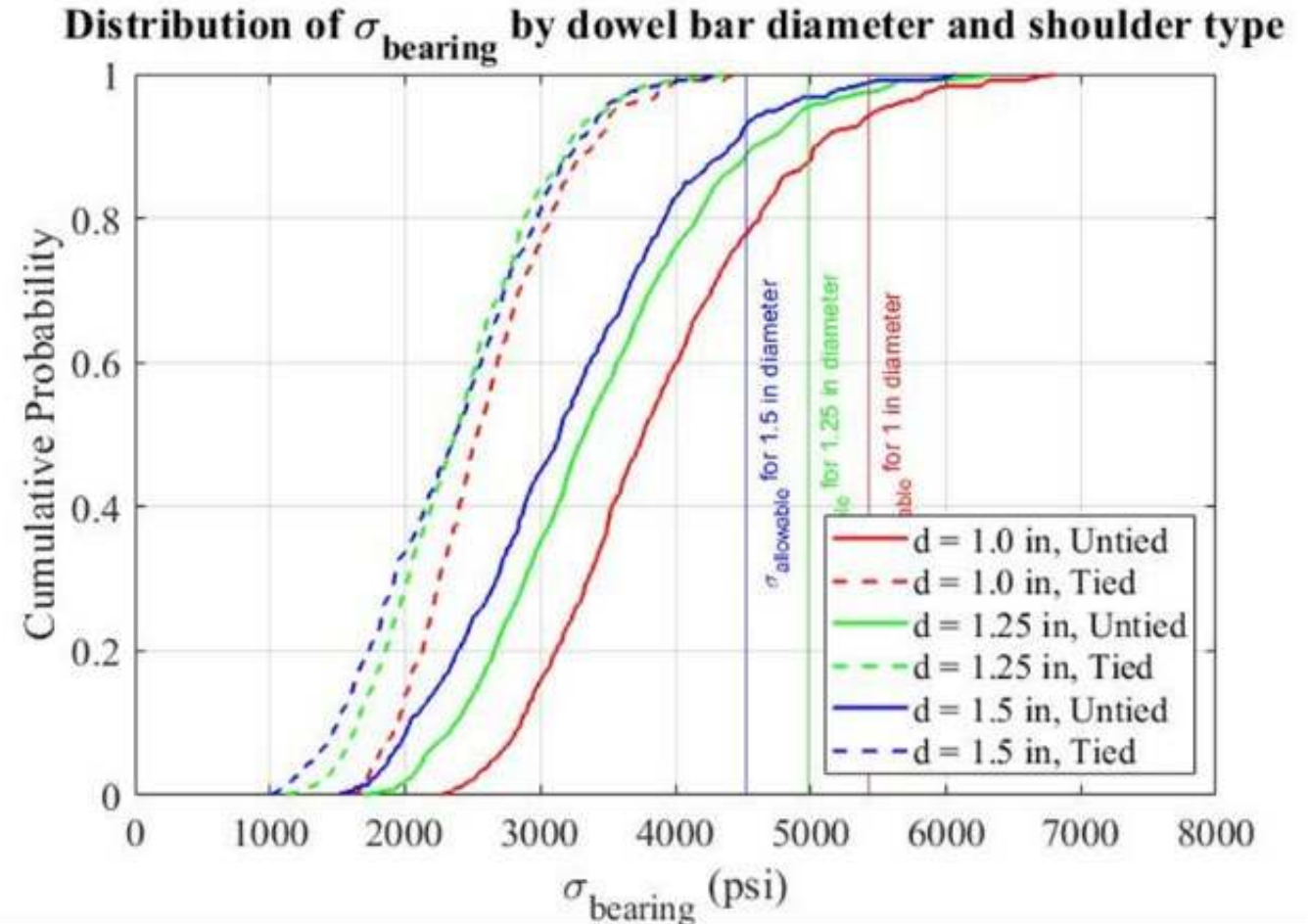
$$\sigma_{allow} = \frac{(4 - d)}{3} f'_c$$

σ_{allow} = allowable bearing stress, psi

d = dia. of the dowel, in.

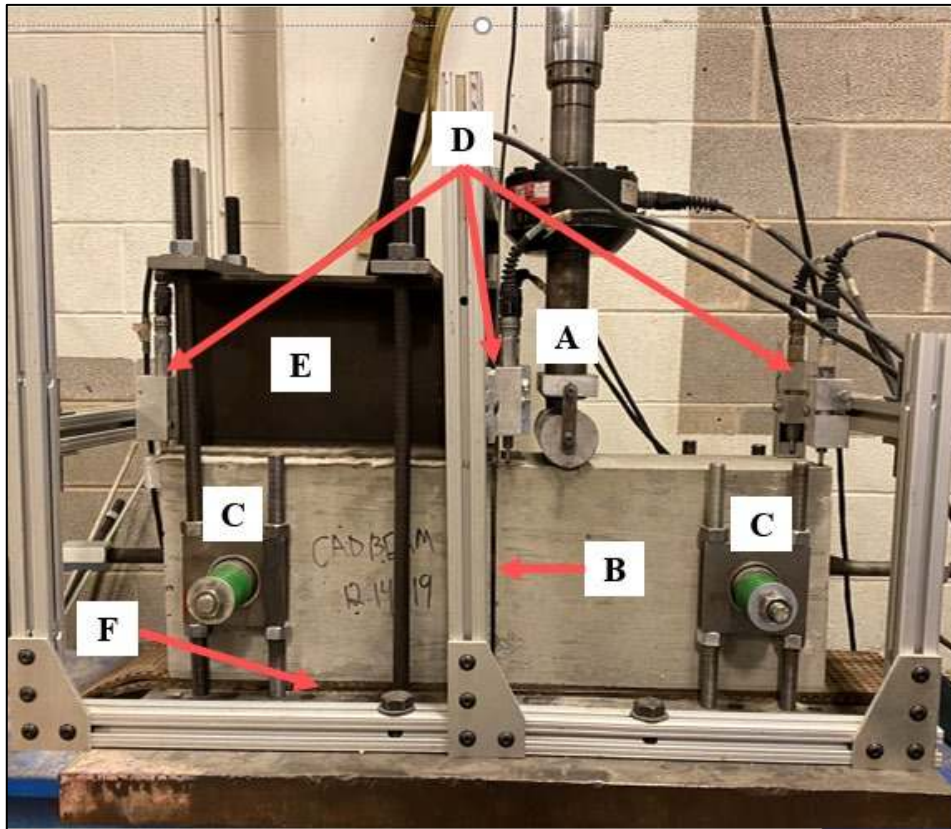
f'_c = concrete compressive strength,

psi

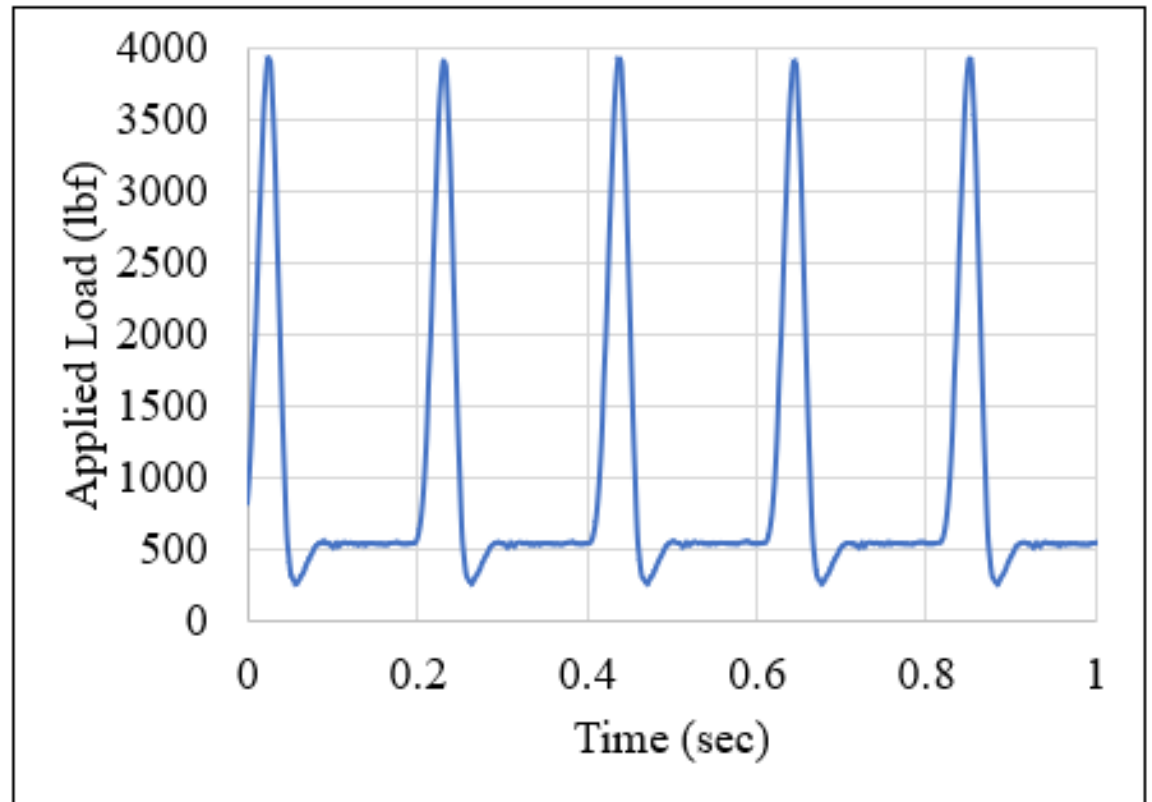


$\kappa = 1500$ ksi/in; w/o aggregate interlock; $f'_c = 5,000$ psi

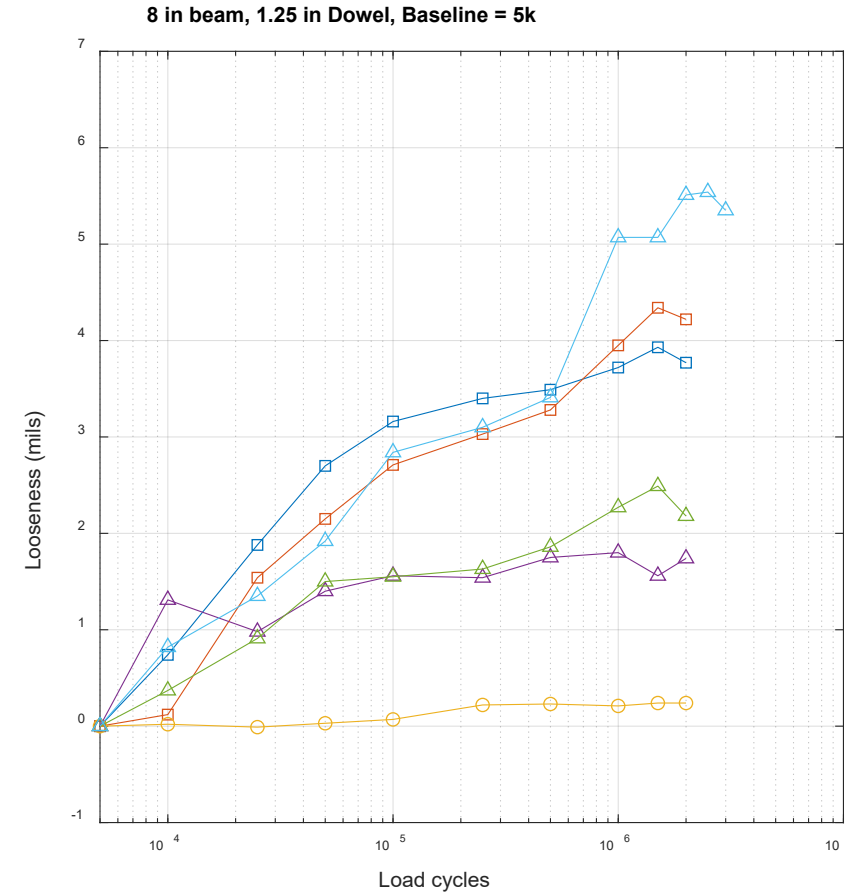
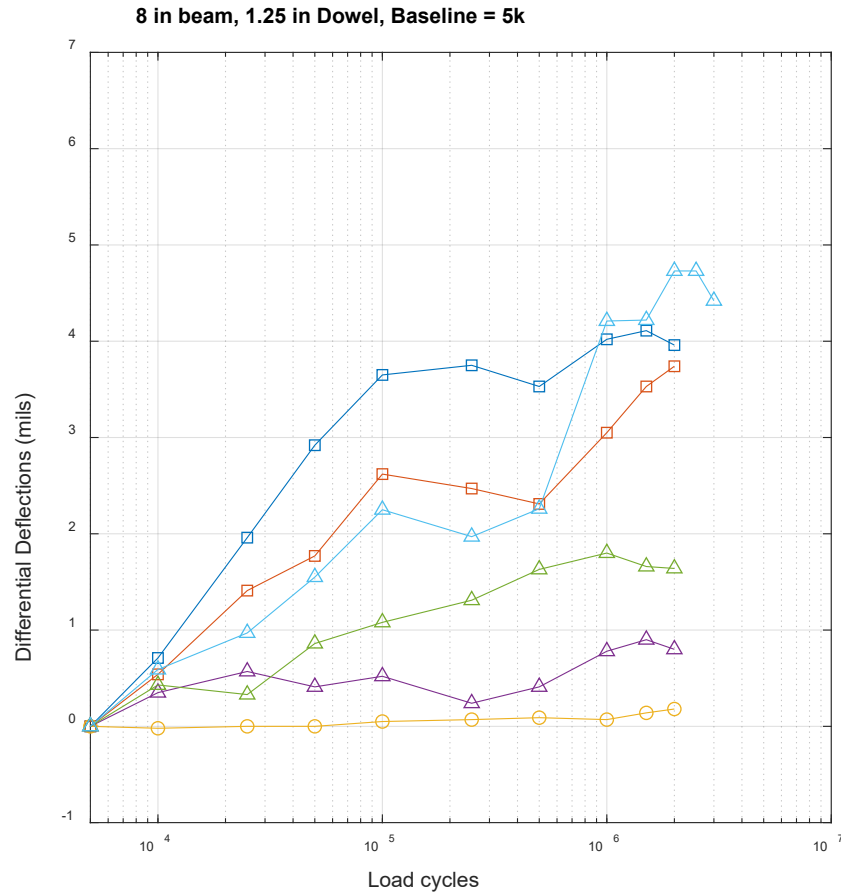
Laboratory investigation



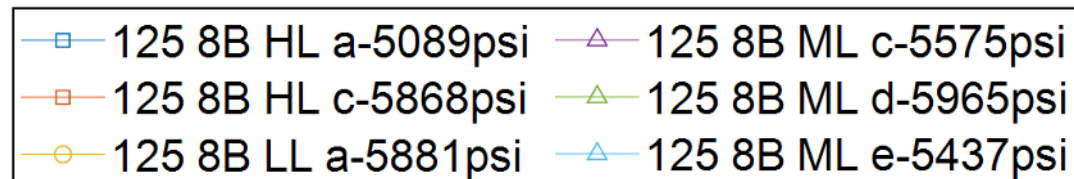
- A – load head
- B – joint
- C – bearings
- D – sensors
- E – clamp
- F – simulated base



Effect of load

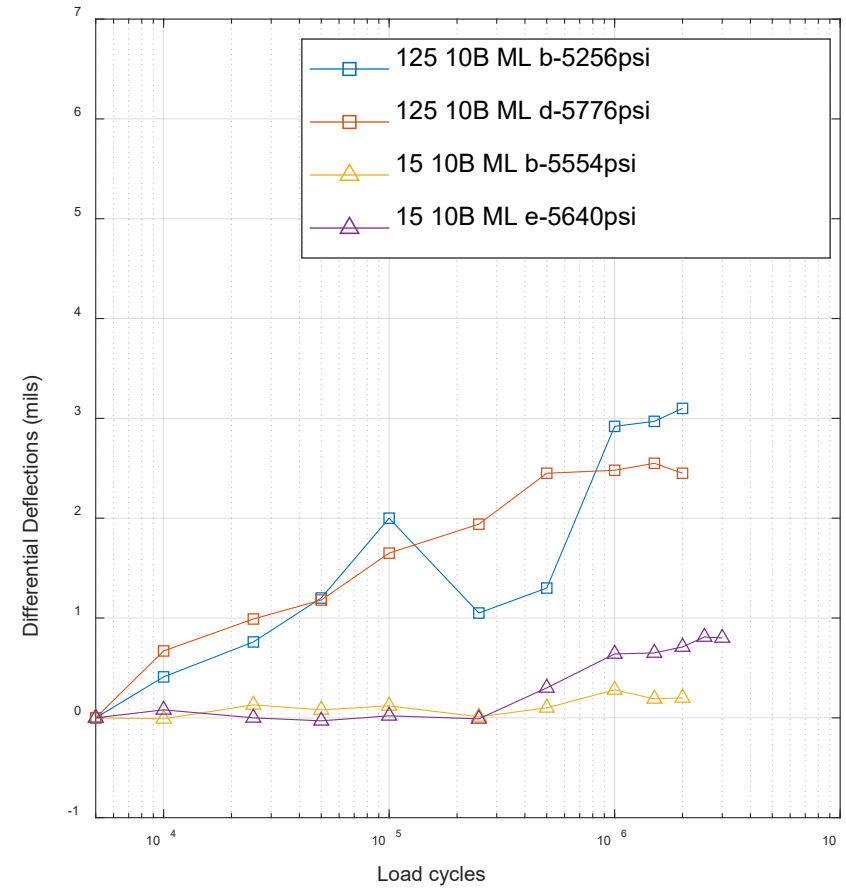


Note: 125 8B ML e had large void around dowel which caused large deflections

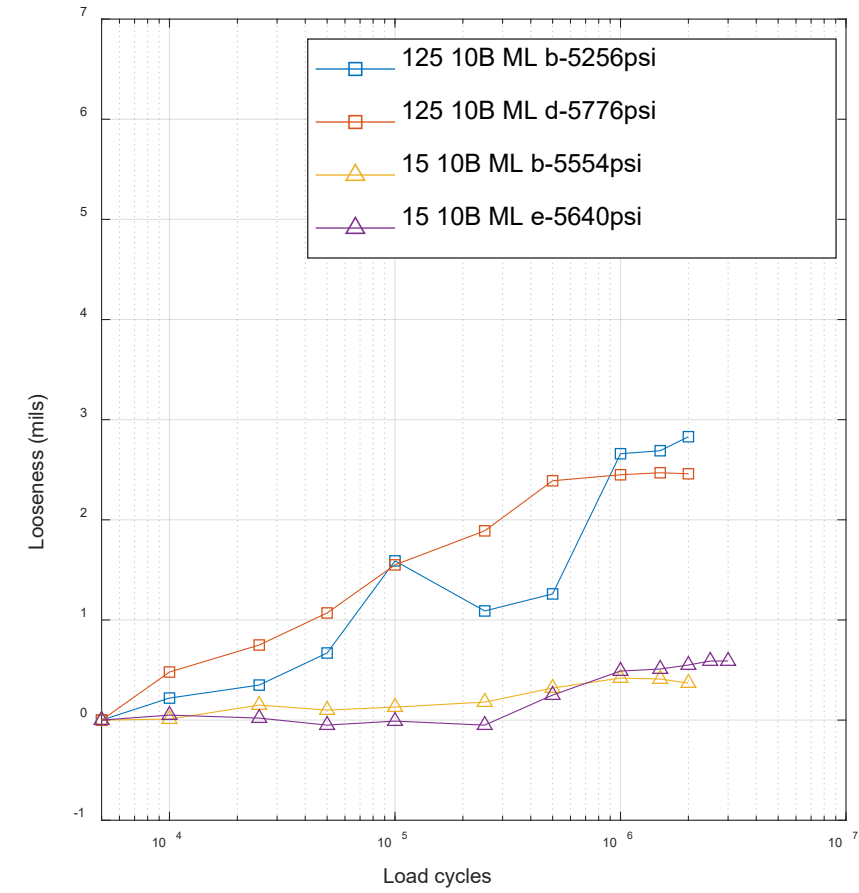


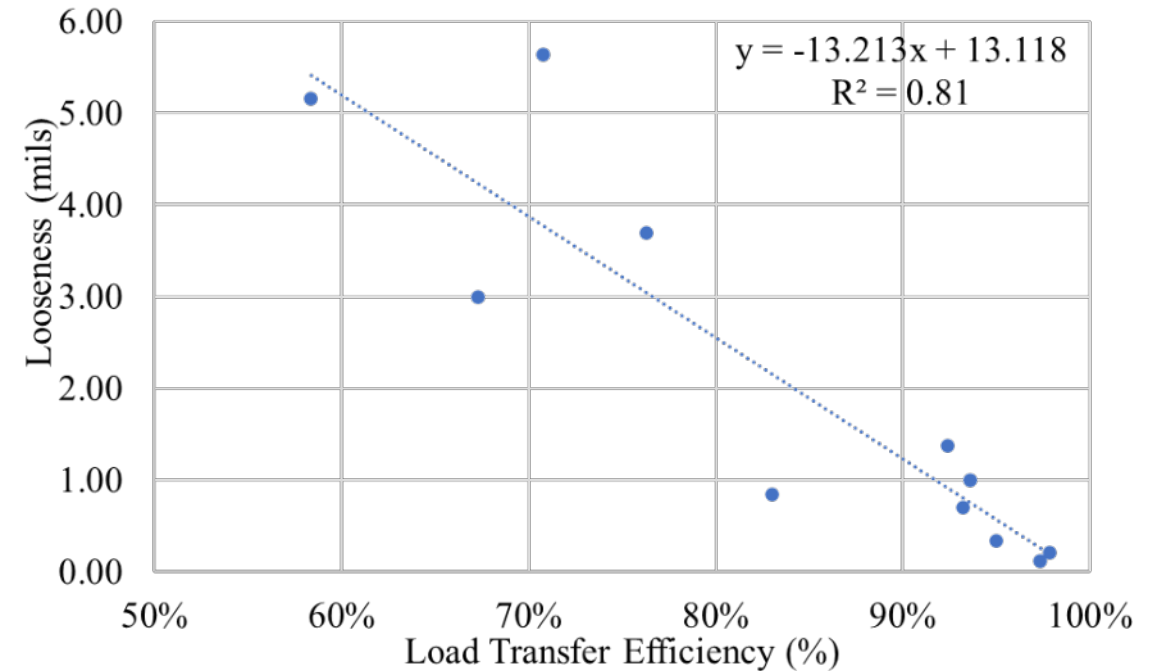
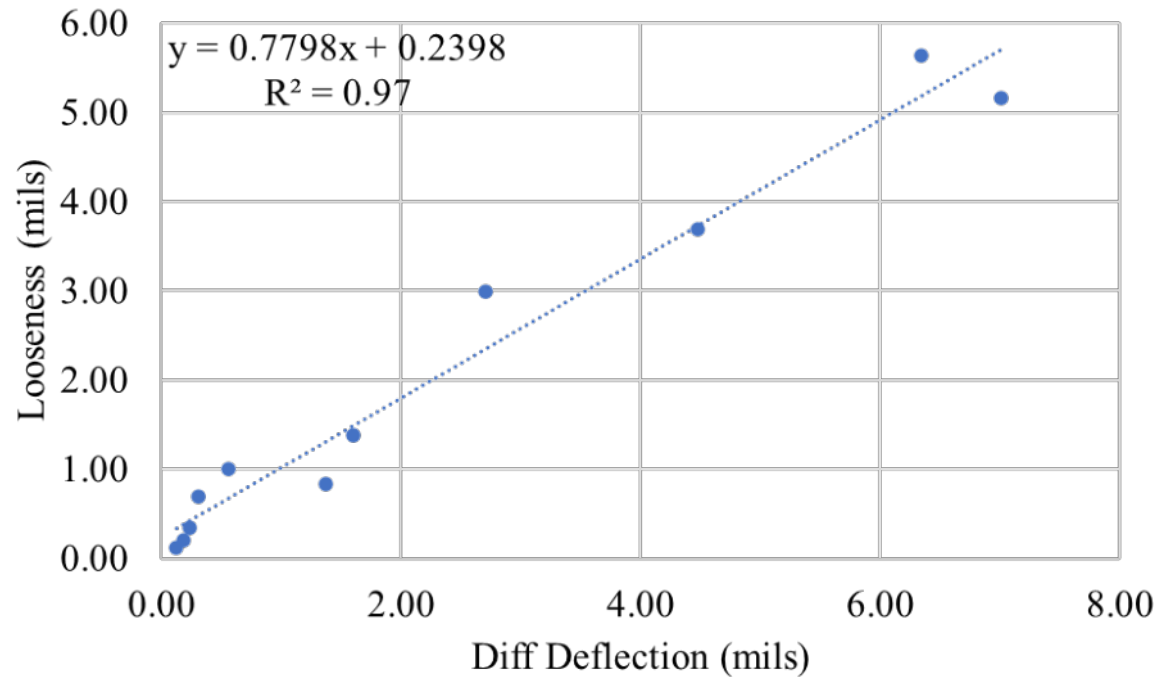
Effect of dowel size

10 in beam, 1.25 and 1.5 Dowel HL, Baseline = 5k



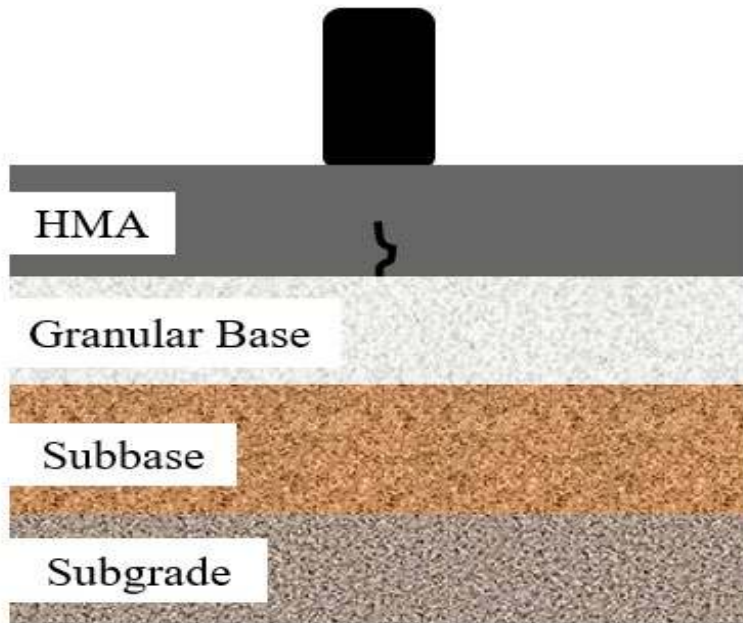
10 in beam, 1.25 and 1.5 Dowel HL, Baseline = 5k





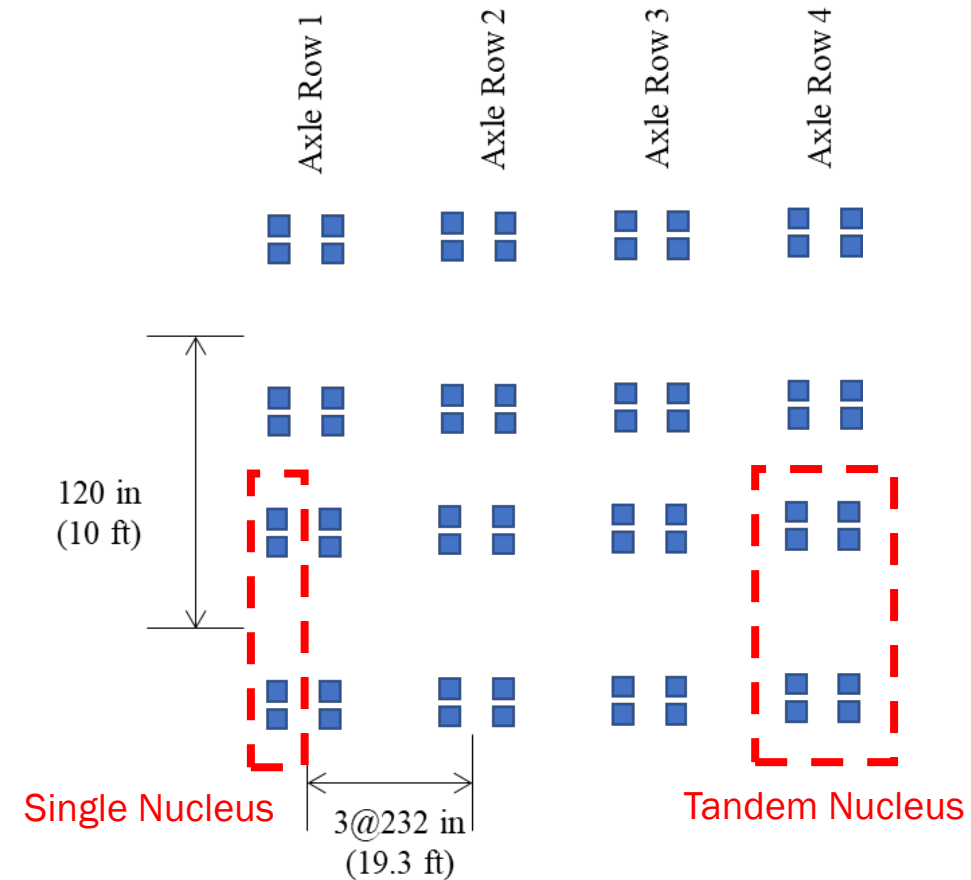
DD correlates better to looseness than LTE

Effect of SLs on rutting and fatigue cracking in asphalt pavements



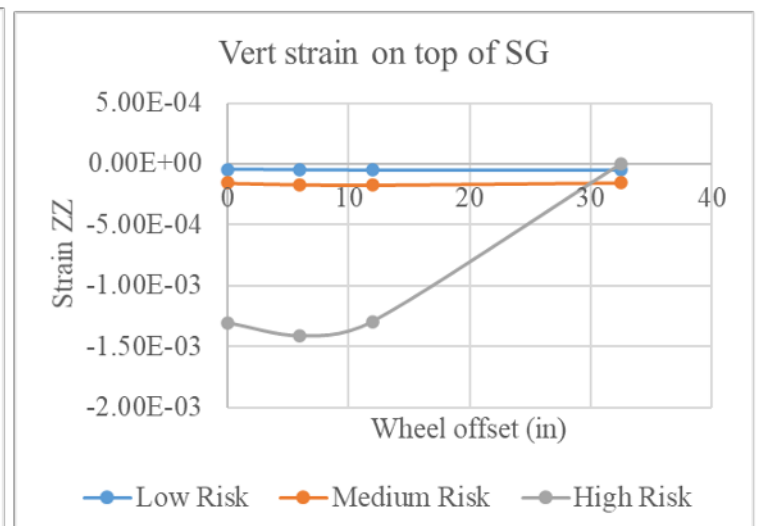
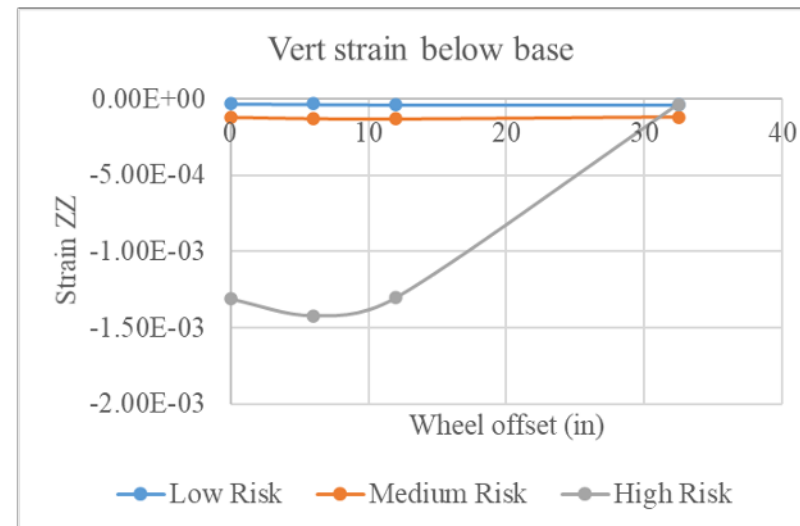
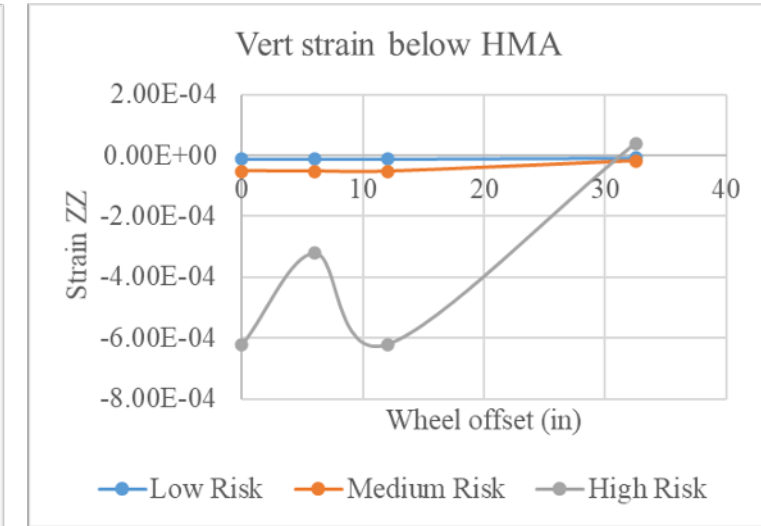
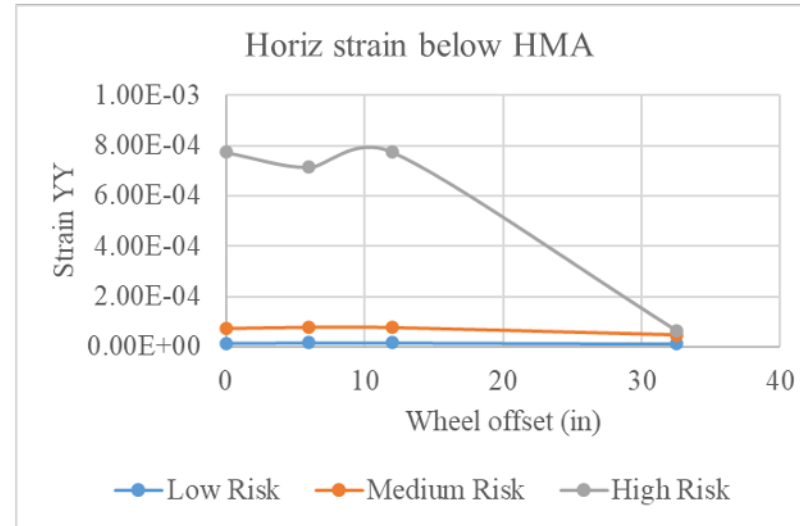
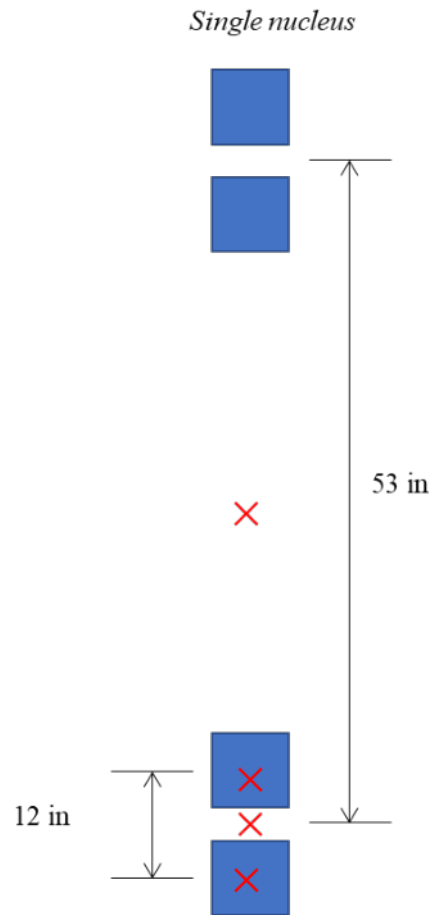
- Rutting
 - Caused by accumulated plastic deformation in each layer
- Shear failure at subgrade
 - Related to compressive strain in the subgrade
- Bottom-up fatigue cracking
 - Caused by horizontal tensile strains at the bottom of the HMA layer

- Layered Elastic Analysis (LEA) to evaluate stresses and strains – **computationally intensive**
- SLs divided into repeating units (“nucleus”) that create the same response each from the pavement – only the nucleus was modeled

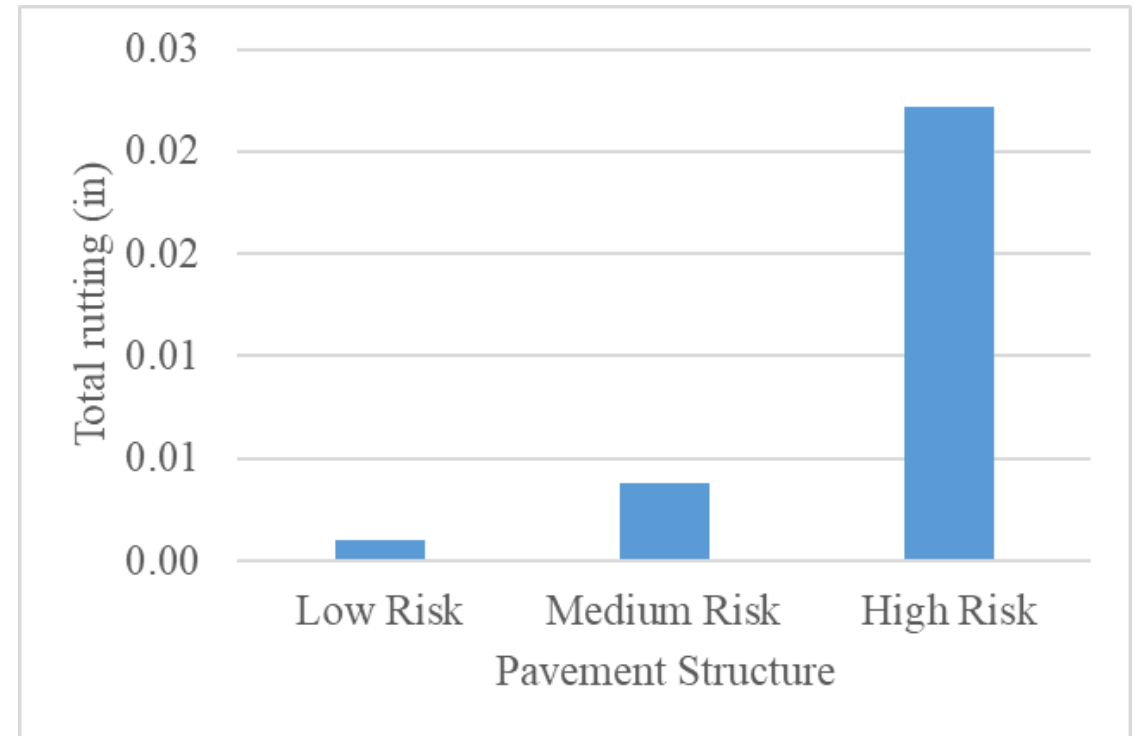
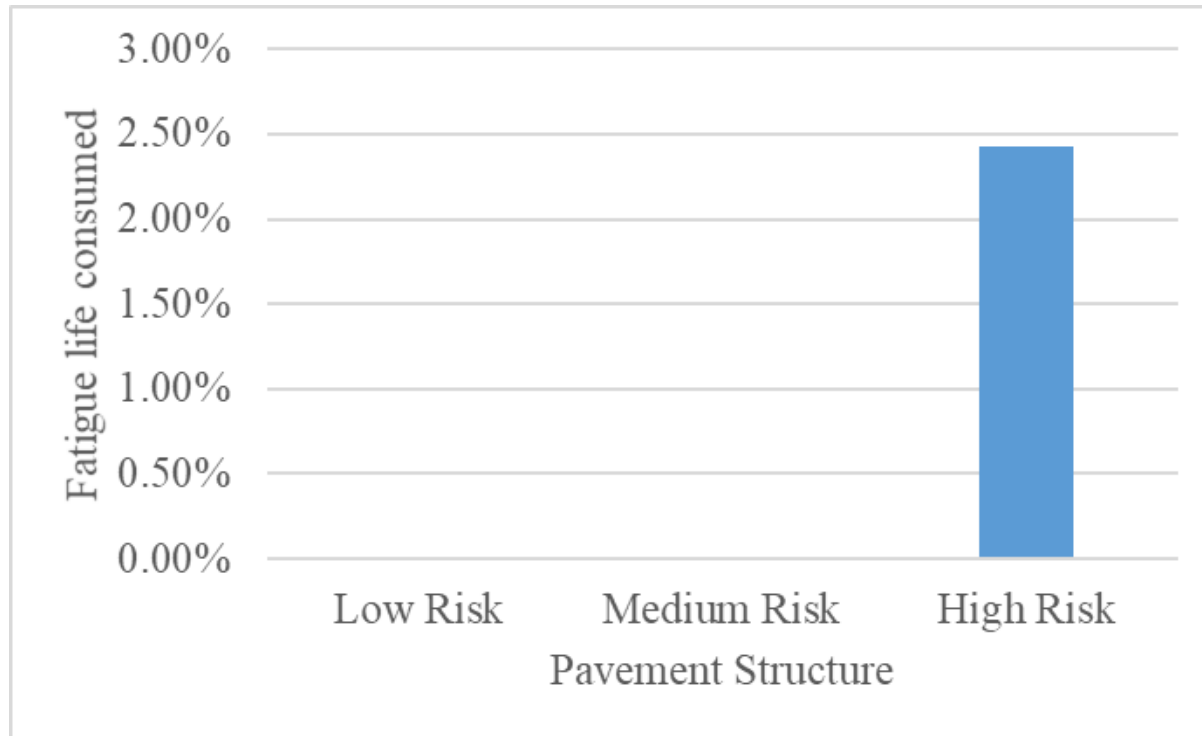


Observation: Single nucleus is adequate for typical SLs in PA

Example Response



Example distresses



- Low, medium, and high risk structures based on thickness and stiffness of pavement layers
- Low risk = thick AC layer (18 in), stiff binder, thick base layer (24 in)
- High risk = thin AC layer (3 in), soft binder, thin base layer (7 in)

Pavement performance prediction for superloads

Critical conditions for fatigue damage and rutting:

- HMA thickness less than 10 in
- Weak base or subbase layers
 - Typically occurs during spring thaw

If these conditions are met, the performance prediction tool should be used

AC response prediction models

Output parameter	Units	R ² adj	Used to calculate
Horizontal strain at the bottom of AC	No units	0.834	Fatigue
Vertical strain at mid-depth of AC	No units	0.498 Low sensitivity	AC Rutting
Vertical strain at mid-depth of base	No units	0.893	Base Rutting
Vertical strain at top of SG	No units	0.925	SG Rutting
Horizontal stress at mid-depth of AC	psi	0.753	AC Rutting
Horizontal stress at mid-depth of AC	psi	0.937	AC Rutting
Vertical stress at mid-depth of AC	psi	0.962	AC Rutting
Horizontal stress at top of SG	psi	0.945	Shear failure
Horizontal stress at top of SG	psi	0.872	Shear failure
Vertical stress at top of SG	psi	0.931	Shear failure

Excel-based tool

Inputs		
Superload:		
Axle load	23126 lbs	Value OK
# of axle rows	8	
Pavement Structure:		
AC thickness	8 in	Value OK
AC modulus	3.00E+05 psi	Value OK
Mid-depth AC temperature	100 °F	
Air voids in AC	7.07 %	
Effective binder content	9.47 %	
Base thickness	10 in	Value OK
Base modulus	3.00E+04 psi	Value OK
Subgrade c	20 psi	
Subgrade phi	20 degrees	
Depth of ground water table	10 ft	
Rutting reliability	85 %	

Damaged AC modulus calculator		
Undamaged AC modulus	3.50E+05	psi
Damaged AC modulus for Adequate AC pavement (0-8% cracking)	3.33E+05	psi
Damaged AC modulus for Marginal AC pavement (8-20% cracking)	3.06E+05	psi

Typical c, phi values of subgrade materials		
Material	c (psi)	phi (°)
Rock	1500	30
Sand	0	35
Gravel	0	35
Silt	12	34
Clay	20	20
Loose sand	0	33
Medium sand	0	40
Dense sand	0	40
Gravel with some sand	0	42

After one pass of the Superload:		
Fatigue damage is approx. equivalent to	30	ESALs
Total rutting =	0.0094	in
Shear failure?	No	

Pavement ME fatigue damage model

Pavement ME rutting model

Mohr-Coulomb shear failure of subgrade

Critical conditions for fatigue cracking:

- Asphalt shoulder
- PCC thickness < 10 in
- Axle loads of 22 kips (single) or 36 kips (tandem) or greater
 - Continuous axles do not cause significant damage
- Temperature gradients > 2.5 °F/in

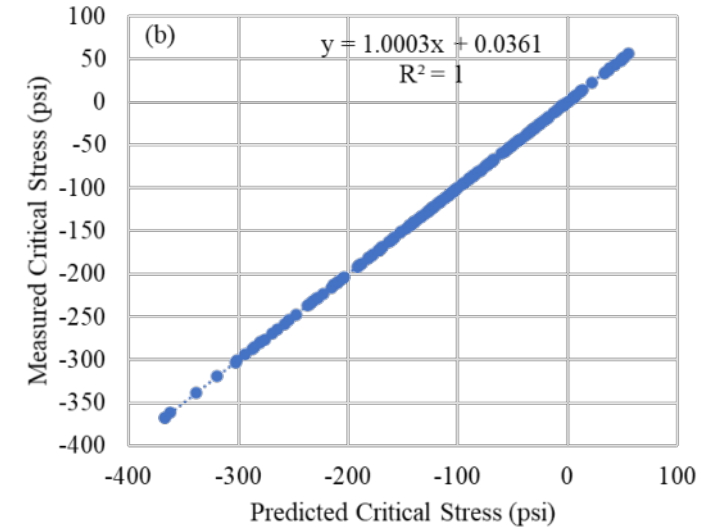
If these conditions are met, the performance prediction tool should be used

PCC stress prediction

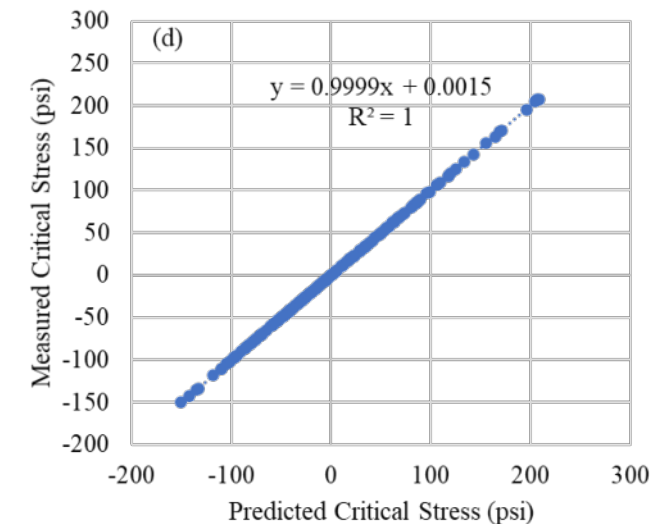
- Only positive gradients were found to be critical previously and are modeled in the tool
- Artificial Neural Network model to predict maximum stresses

SL category	Sign of the Temperature Gradient	R^2 adj
Single	Positive	0.99
Tandem	Positive	0.99

Single SL



Tandem SL



 Excel-based tool

Single SL

Inputs		
Superload:		
Axle load	22.931 kips	Value OK
Number of rows of single axles in SL	10	Value OK
Number of superload trucks	100	Value OK
Pavement Structure:		
PCC thickness	7 in	Value OK
Concrete thermal coef of expansion	5.50E-06 /F	Value OK
Temperature gradient in slab	2.5 F/in	Value OK
Transverse joint LTE	90 %	Value OK
Subgrade k-value	200 psi/in	Value OK

Tandem SL

Inputs		
Superload:		
Axle load	46.252 kips	Value OK
Number of rows of tandem axles in SL	4	Value OK
Spacing between tandem axles	14.08333 ft	Value OK
Number of superload trucks	100	Value OK
Pavement Structure:		
PCC thickness	7 in	Value OK
Concrete thermal coef of expansion	5.5E-06 /F	Value OK
Temperature gradient	2.5 F/in	Value OK
Transverse joint LTE	90 %	Value OK
Subgrade k-value	200 psi/in	Value OK

From Pavement ME
fatigue damage model

For this superload truck:		
Allowable number of truck repetitions	2.57E+03	
Actual number of truck repetitions	1.0E+02	
Fatigue life consumed	3.9%	

- SLs have unique axle configurations and heavy loads, and hence need special consideration
- PCC fatigue critical conditions:
 - Heavy loads and high pos. temp. gradients are critical conditions; non-linear damage needs to be considered
- PCC faulting critical conditions:
 - Heavy loads, high pos. temp. gradients, no aggregate interlock, and HMA shoulders are critical conditions
- AC critical conditions:
 - Heavy loads, thin and soft AC and base layers
- **A single pass of a SL will not cause failure but will cause disproportionately high damage as compared to a single pass of a standard axle**

- Funded provided by Pennsylvania Department of Transportation and Federal Highway Administration
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 - Mr. Nathaniel Buettner
 - Mr. Charles Donnelly
 - Dr. Sushobhan Sen, PhD
 - Dr. Naser Sharifi, PE, PhD



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Questions?